

Satellite Characterization of Biomass Burning and Smoke Emissions in Africa

A satellite image of West Africa, showing a dense distribution of red dots across the landmass, representing biomass burning events. The image is overlaid with a grid of latitude and longitude lines. The text is positioned in the upper left and lower left areas of the image.

Charles Ichoku (NASA/GSFC, UMD/ESSIC)

Acknowledgement

Yoram J. Kaufman

Martin J. Wooster

Gareth Roberts

Louis Giglio

Luke Ellison

Thomas Diehl

Mian Chin

Shahid Habib

Robert Cahalan

Charles Gatebe

NASA EarthObservatory Team

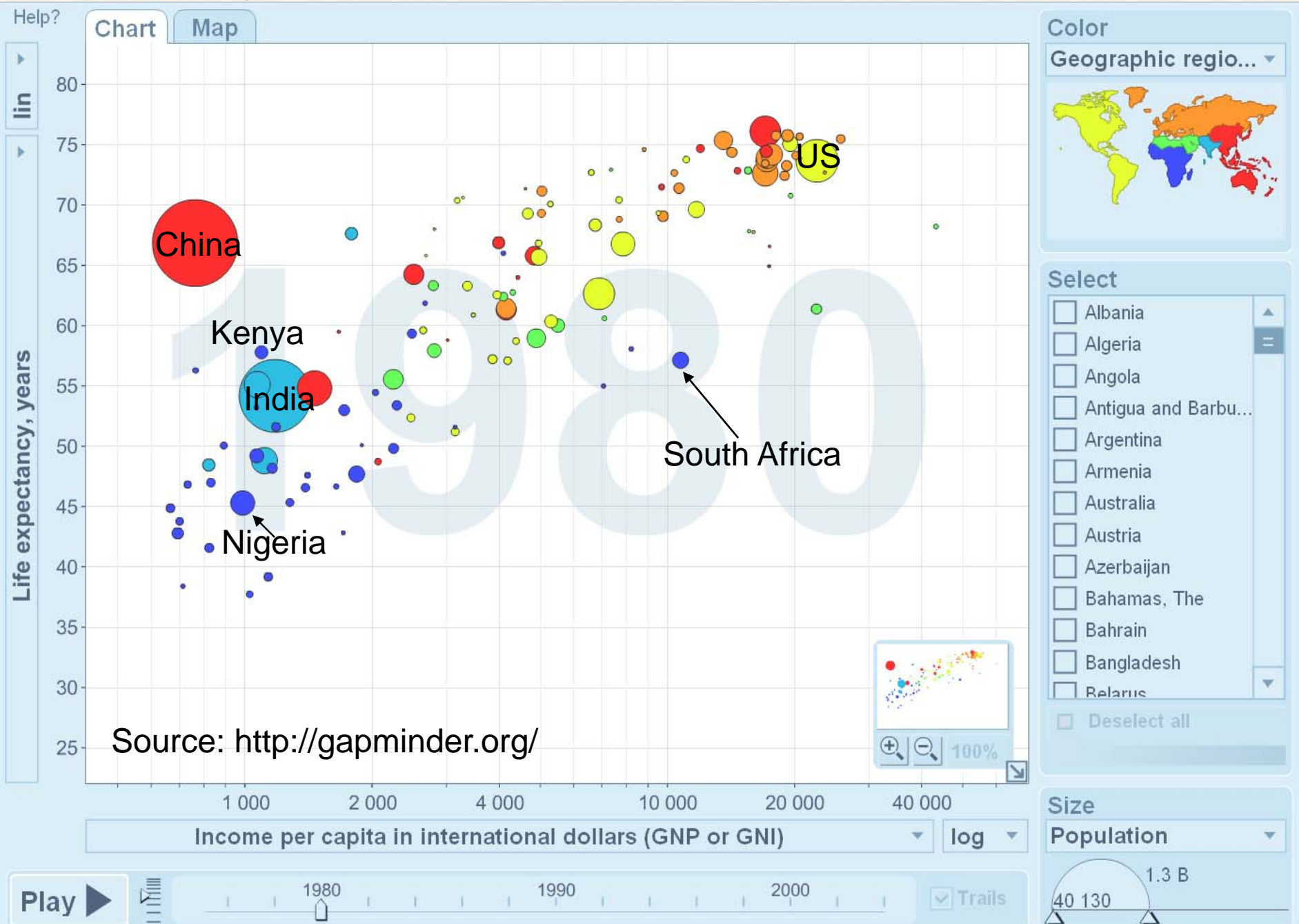
Presented at the GDEST Conference, Cape Town, South Africa, 17-19 March, 2008

Session: Observing Africa

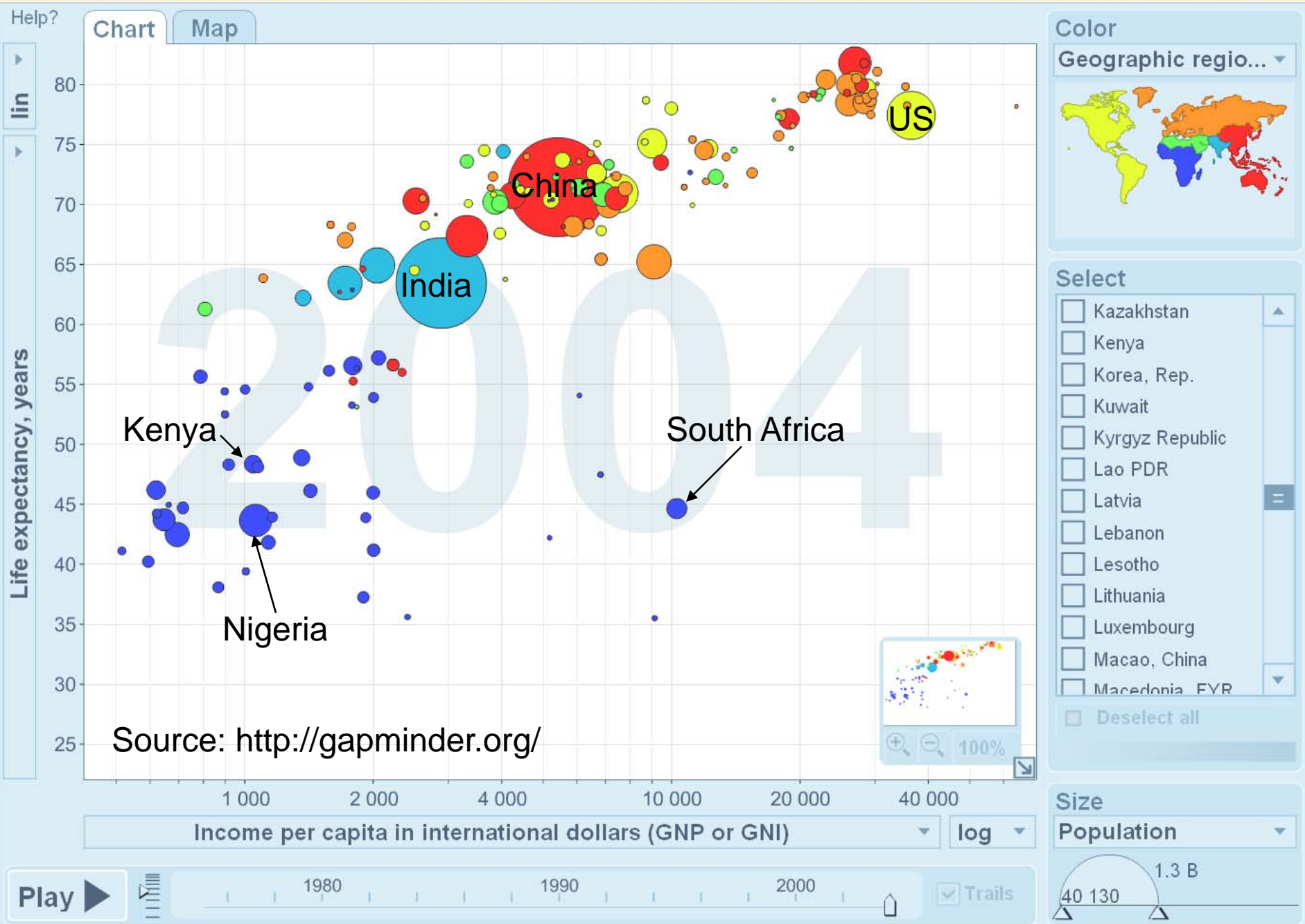
Fires in West Africa from Aqua-MODIS 29-Dec-2004, 13:40 UTC (Courtesy: NASA EarthObservatory)

- African Overview.
- Satellite Remote Sensing of Fires.
- Fire Radiative Power (FRP)
Characterization.
- Estimating Smoke Emissions from
FRP.
- Application of Emissions to Atmos
Modeling.

Africa in the global map of “Income per capita” and “Life Expectancy”



Africa in the global map of “Income per capita” and “Life Expectancy”

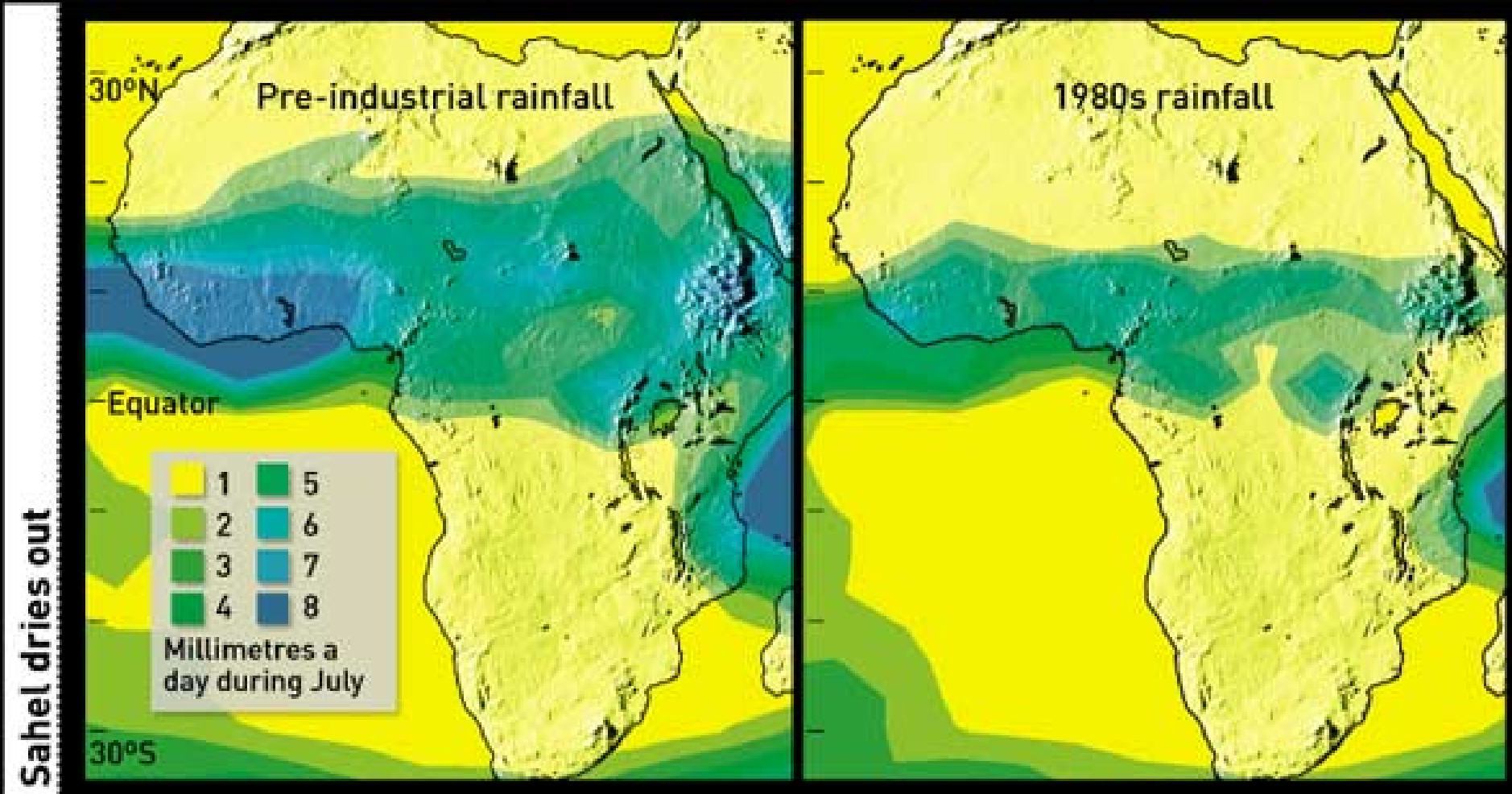


Some Factors responsible for “Poverty” and “Death” in Africa

- Disease outbreaks
- Water pollution and scarcity
- Air Pollution from Agricultural Fires and Dust
- Drought (massive starvation)
- Desertification (global change)
- Flooding
- Invasive Species (e.g. Locusts)
- Poor Planning and Poor Technology
- Poor Management
- Wars and bad political systems.

African Droughts

(New Scientist: 19:00 12 June 2002)



“Although the droughts have had climate experts scratching their heads, the impacts have been obvious. During the worst years, between 1972 and 1975, and 1984 and 1985, up to a million people starved to death.”

African Air Pollution

(NASA EarthObservatory: The seasonal agricultural burning in tropical Africa dotted the continent with fires on January 17, 2007.)



“Although the fires are not necessarily immediately hazardous, such large-scale burning can have a strong impact on weather, climate, human health, and natural resources. Also obvious in the image is the dust spreading west-southwest from the Bodele Depression at the southern edge of the Sahara Desert. The remains of an ancient lake bed, the Bodele Depression is probably the largest single source of windblown dust in the world.”

REPORTS

Measurement of the Effect of Amazon Smoke on Inhibition of Cloud Formation

Ilan Koren,^{1,2*} Yoram J. Kaufman,¹ Lorraine A. Remer,¹ Jose V. Martins^{1,3}

Urban air pollution and smoke from fires have been modeled to reduce cloud formation by absorbing sunlight, thereby cooling the surface and heating the atmosphere. Satellite data over the Amazon region during the biomass burning season showed that scattered cumulus cloud cover was reduced from 38% in clean conditions to 0% for heavy smoke (optical depth of 1.3). This response to the smoke radiative effect reverses the regional smoke instantaneous forcing of climate from -28 watts per square meter in cloud-free conditions to $+8$ watts per square meter once the reduction of cloud cover is accounted for.

The net effect of aerosols on the atmospheric radiation budget and climate constitutes the greatest uncertainty in attempts to model and predict climate (1). Aerosols can counteract regional greenhouse warming by reflecting solar radiation to space or by enhancing cloud reflectance (2) or lifetime (3, 4). However, aerosol absorption of sunlight is hypothesized to slow down the hydrological cycle and influence climate in ways not matched by the greenhouse effects (5, 6). During periods of heavy aerosol concentration over the Indian Ocean (7) and Amazon basin (8), for exam-

ple, measurements have revealed that absorbing aerosols warmed the lowest 2 to 4 km of the atmosphere while reducing by 15% the amount of sunlight reaching the surface.

Less irradiation of the surface means less evaporation from vegetation and water bodies, and (unless the smoke is concentrated near the surface only) a more stable and drier atmosphere, and consequently less cloud formation. This effect was defined theoretically as a positive feedback to aerosol absorption of sunlight (9) and was termed the semi-direct effect. A similar process, defined as cloud burning by soot, in which solar heating by the aerosol reaches its maximum near the top of the boundary layer, thereby stabilizing the boundary layer and suppressing convection, has been described (10). These cloud simulations were based on aerosol observations of INDOEX (Indian Ocean Experiment) (11) and focused mainly on the amplification of daytime clearing due to aerosol heating.

Reduction of evaporation from the Mediterranean Sea by pollution from northern and eastern Europe was modeled to reduce cloud formation and precipitation over the Mediterranean region (12), in general agreement with measurements (13). However, warming of the atmosphere by similar widespread pollution aerosol over southeastern China was modeled to cause uplift of the polluted air mass over an area of 10 million km^2 , which then was replaced by cooler moist air from the nearby Pacific Ocean, causing an increase in precipitation and flooding that fits observations from this region in recent years (14).

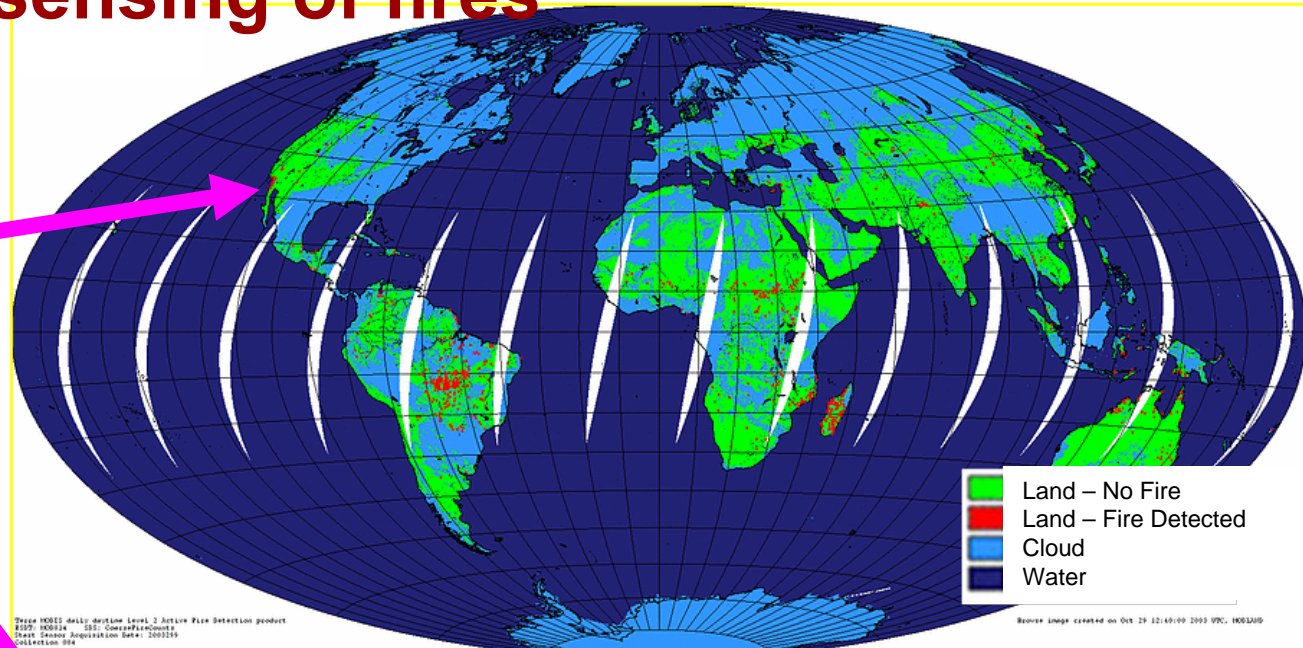
Here, using data from the MODIS-Aqua space instrument, we report measurements of the effect of smoke on cloud formation over the Amazon basin during the dry season (August–September) of 2002—namely, the reduction of the fraction of scattered cumulus clouds with the increase in smoke column concentration.

The area is under the influence of a regional high-pressure zone above a surface boundary layer and is associated with lower precipitation, land clearing, and biomass burning. The moisture source for the cloud formation and precipitation in the region is water vapor evaporated locally through plant evapotranspiration and moisture transported from the Atlantic Ocean (15), each responsible for half of the moisture that falls as precipitation. Easterly winds carry the moisture from the Atlantic Ocean throughout the Amazon basin until they reach the barrier of the Andes, where they decrease in velocity and veer either north or south (16) (Fig. 1). The scattered cumulus clouds (also called boundary layer clouds) emerge regularly in the morning over the eastern shore. By local

¹NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771, USA. ²National Research Council, Washington, DC 20001, USA. ³Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Baltimore, MD 21250, USA.

*To whom correspondence should be addressed. E-mail: ilank@climate.gsfc.nasa.gov

Satellite remote sensing of fires



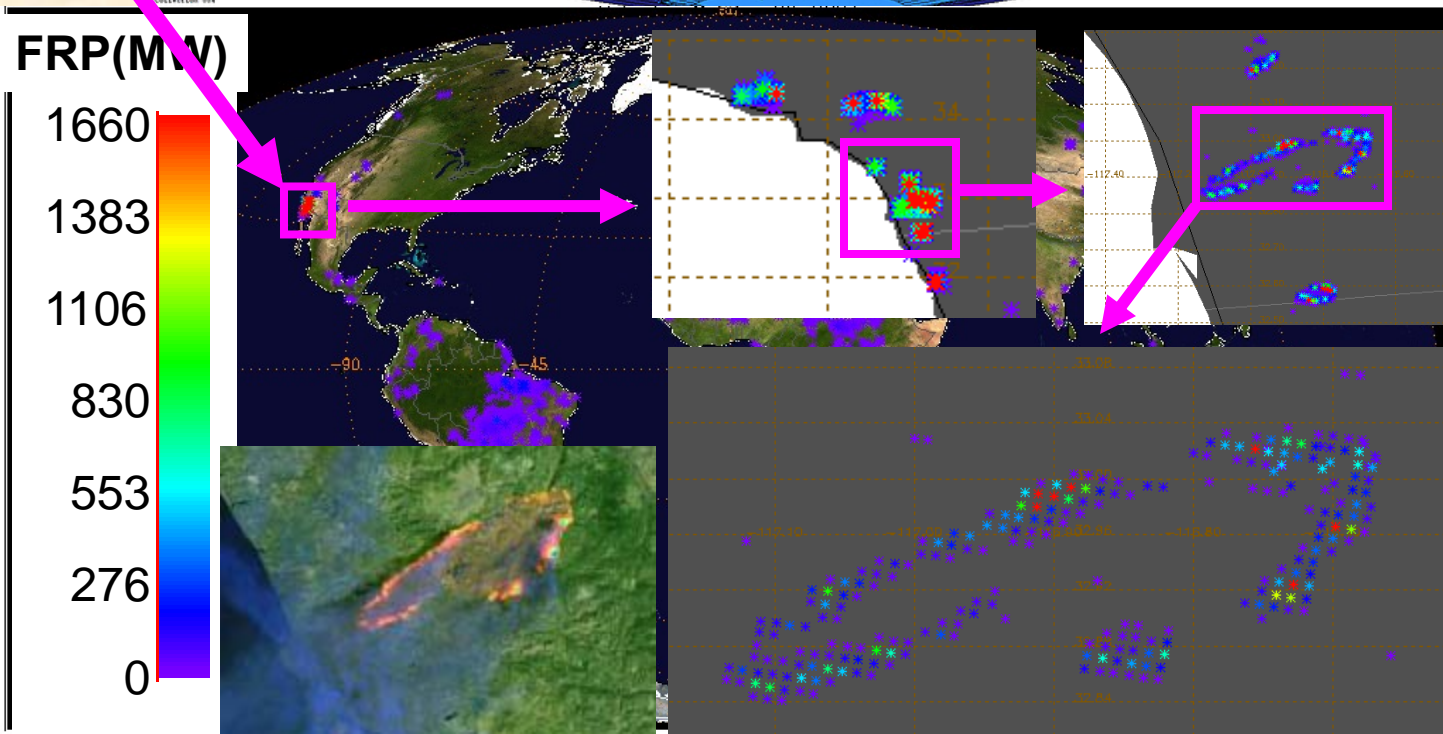
➤ Where?

➤ How Big?

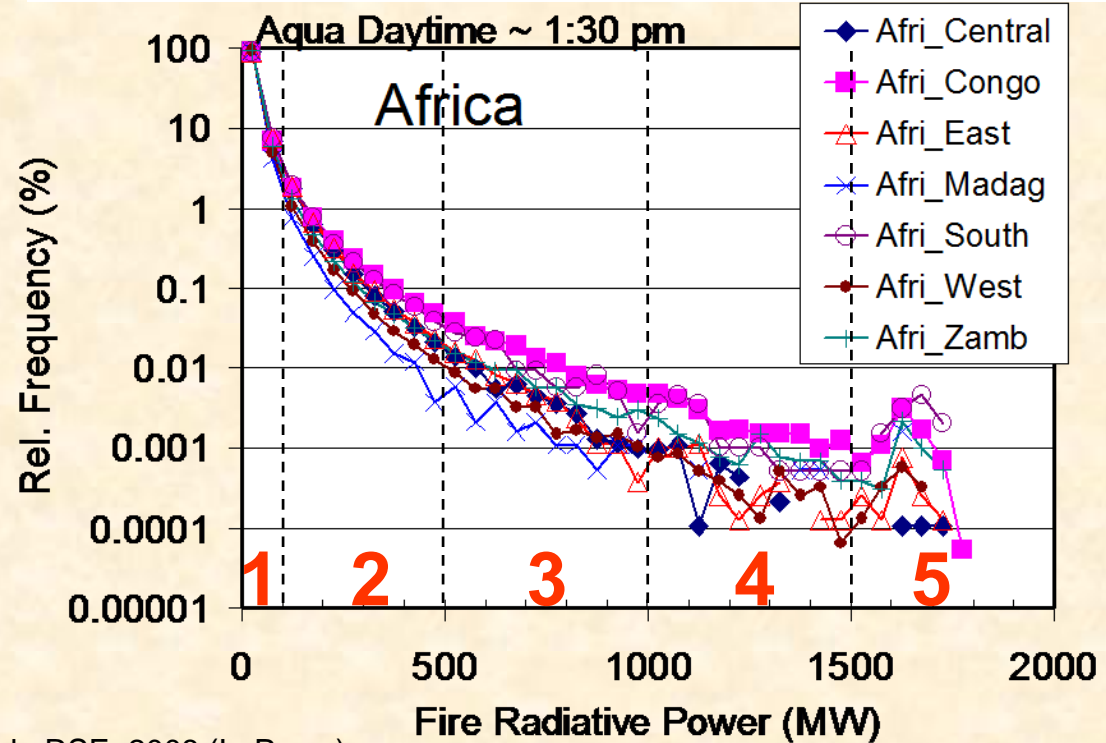
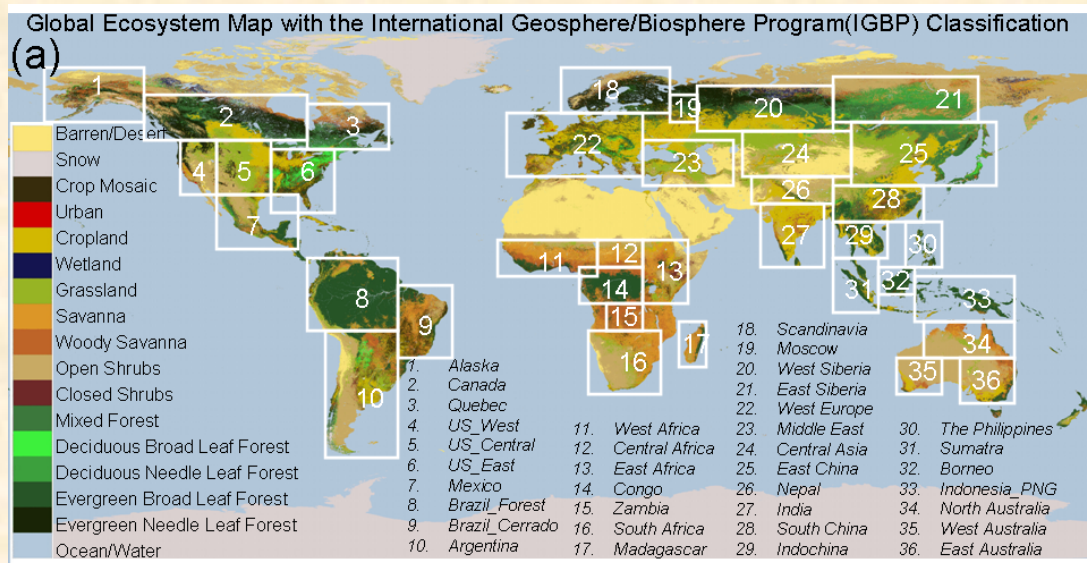
➤ Where to deploy crew?

➤ How much smoke emitted?

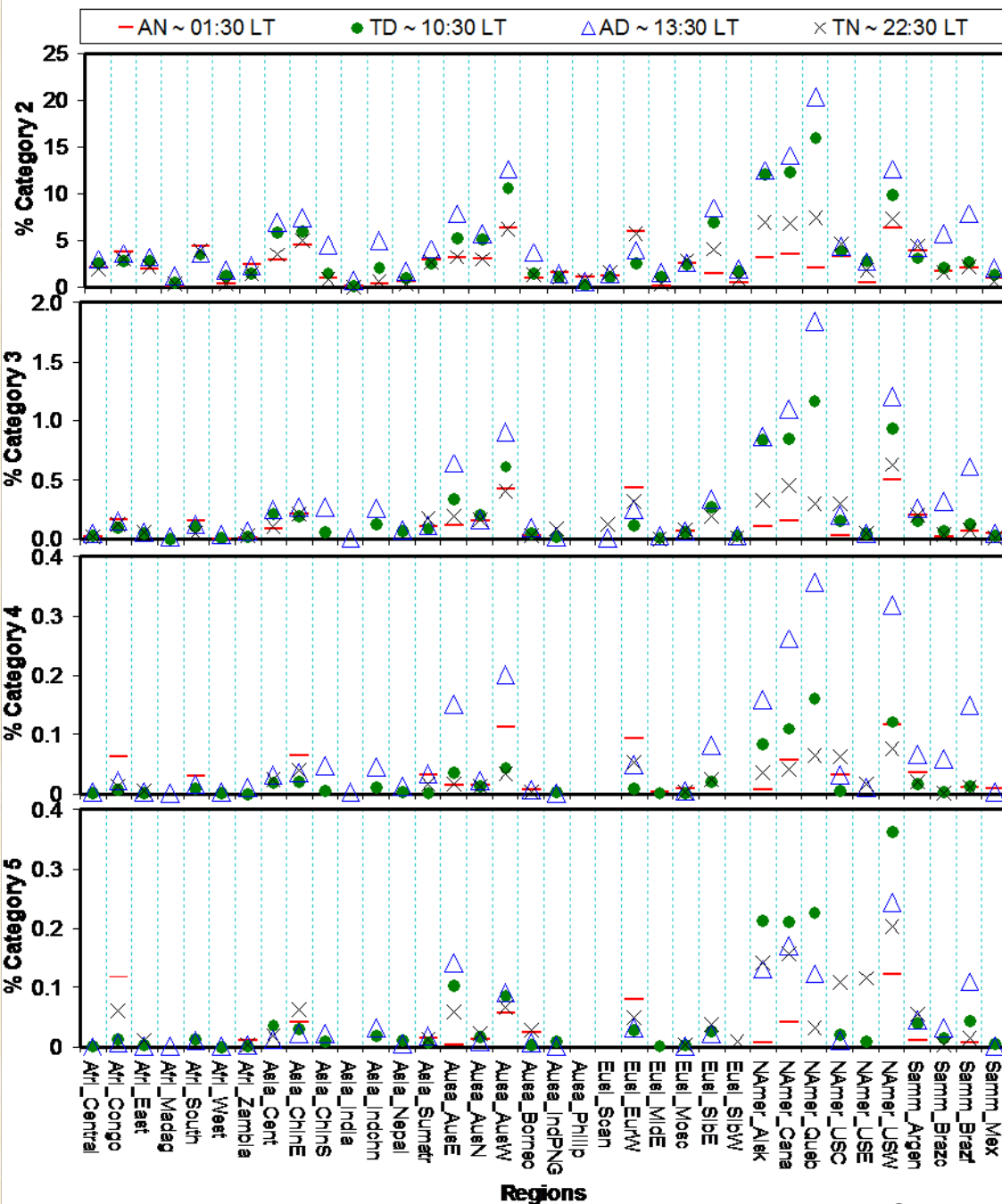
➤ What is it doing?



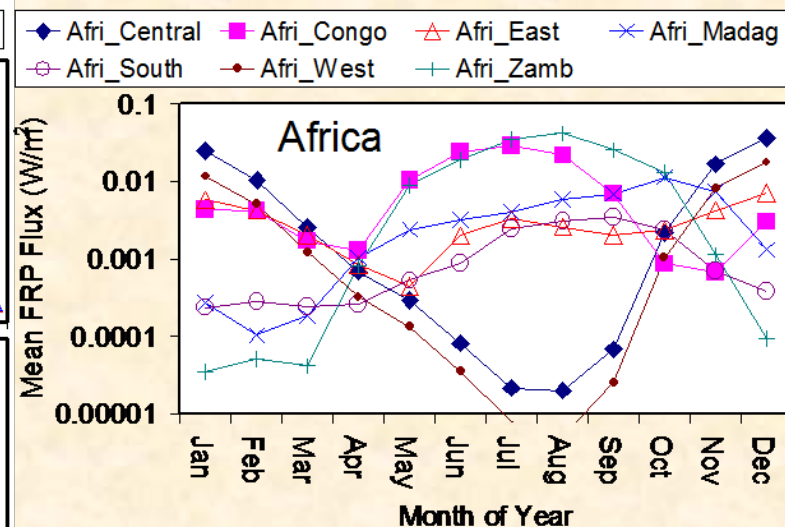
Fire Characterization using MODIS Fire Radiative Power (FRP)



Regional Distribution of Fire Categories



Regional Monthly Mean Heat Flux



Comparison with Peak Months in Other Regions

Africa : $\sim 0.05 \text{ W/m}^2$
 Asia : ~ 0.03 (Indochina)
 others < 0.005
 S. America : ~ 0.02
 Australia : ~ 0.01
 N. America : ~ 0.005
 Siberia : ~ 0.004
 Europe : ~ 0.002

Revising the smoke emissions estimation approach

Traditional Emissions Estimation Approach

Emissions = Emission Factor (EF) × Biomass Mass (BM)

$$\text{BM} = A \times B \times \alpha \times \beta$$

Where,

A=Area burned

B=Biomass density

α =Above ground biomass proportion

β =Combustion Efficiency

FRE-based smoke emissions estimation approach

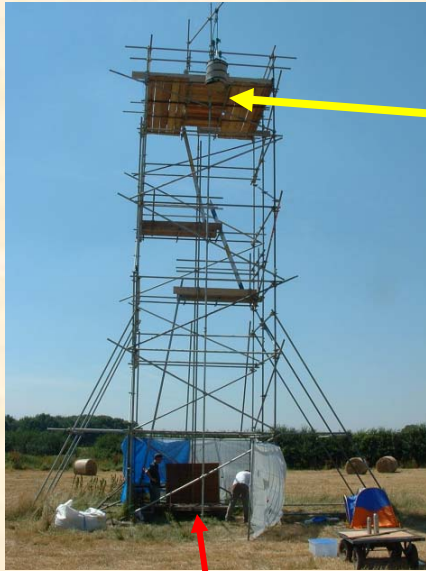
(1) Emissions = EF × BM (from FRE)

[Wooster]

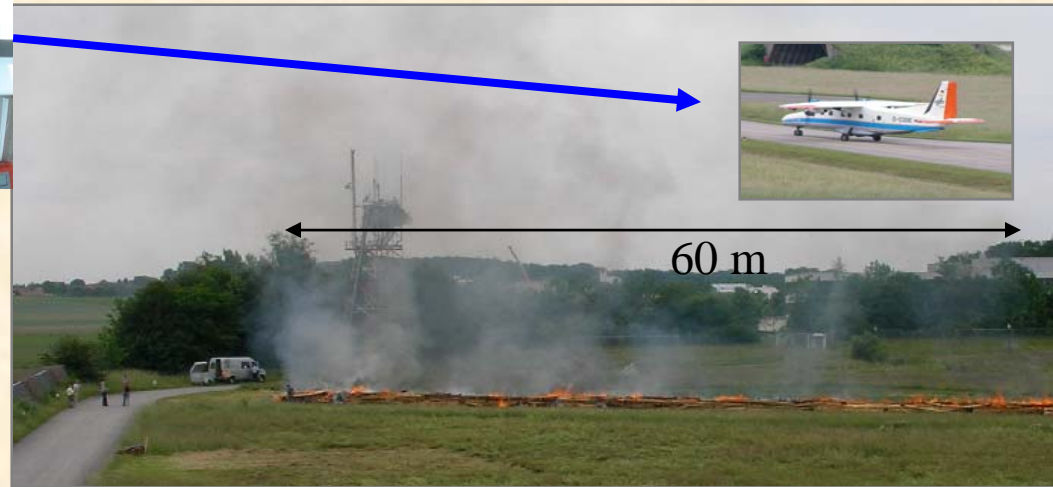
(2) Emissions = Emission Coeff. (Ce) × (FRP or FRE)

[Ichoku]

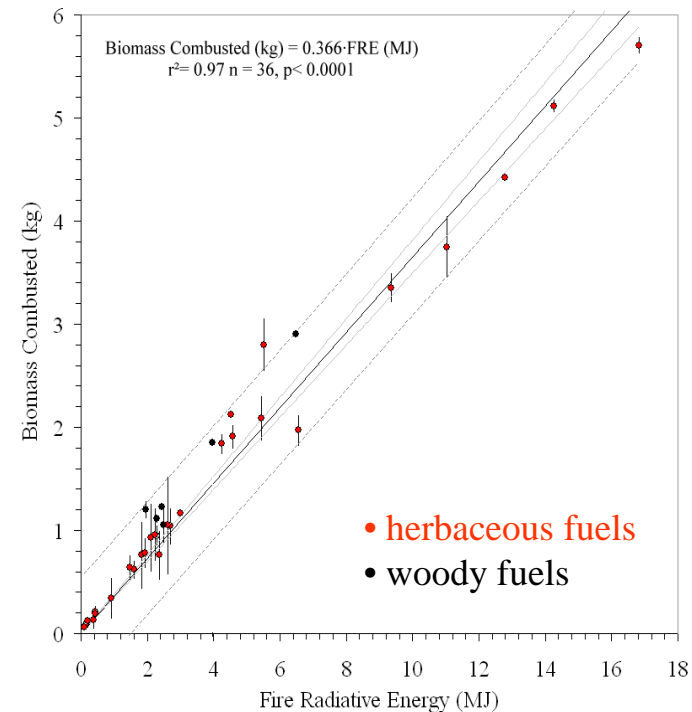
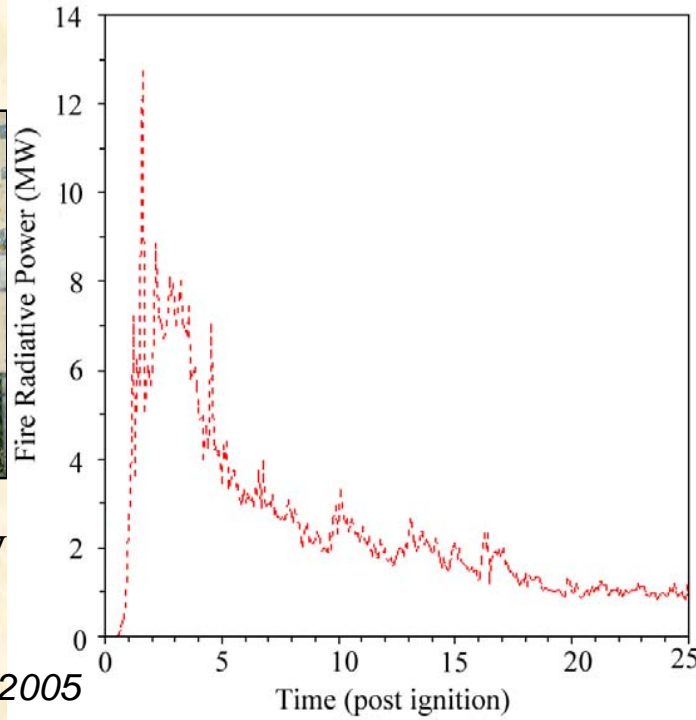
Fire Radiative Energy and Burned Biomass



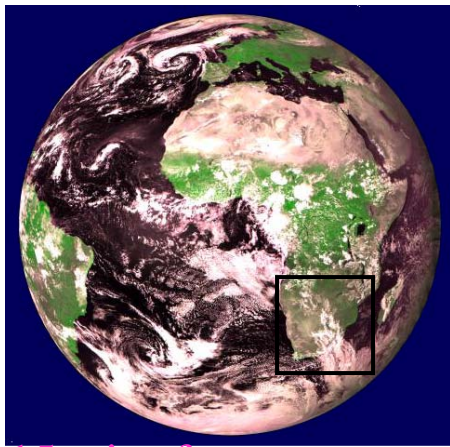
Spectro-
Radiometer
or IR Camera



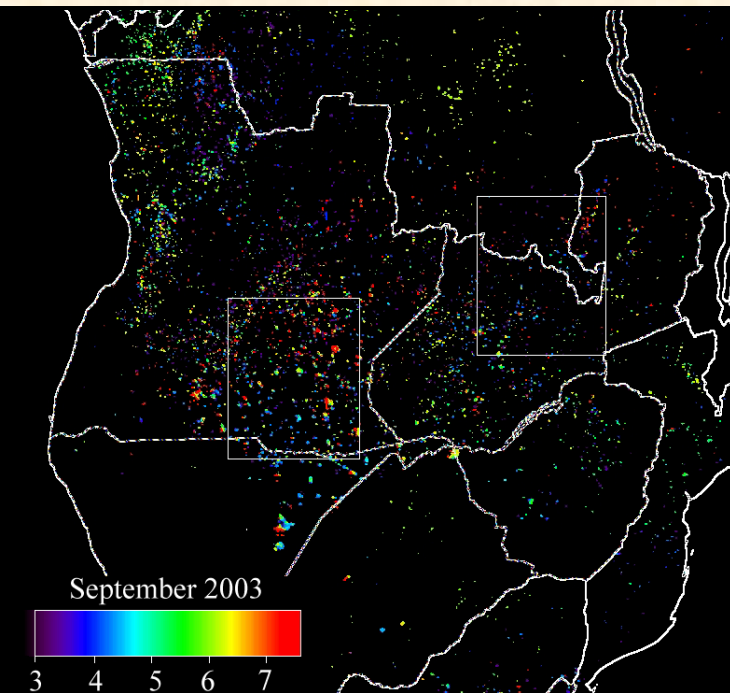
Spectro-radiometer FOV



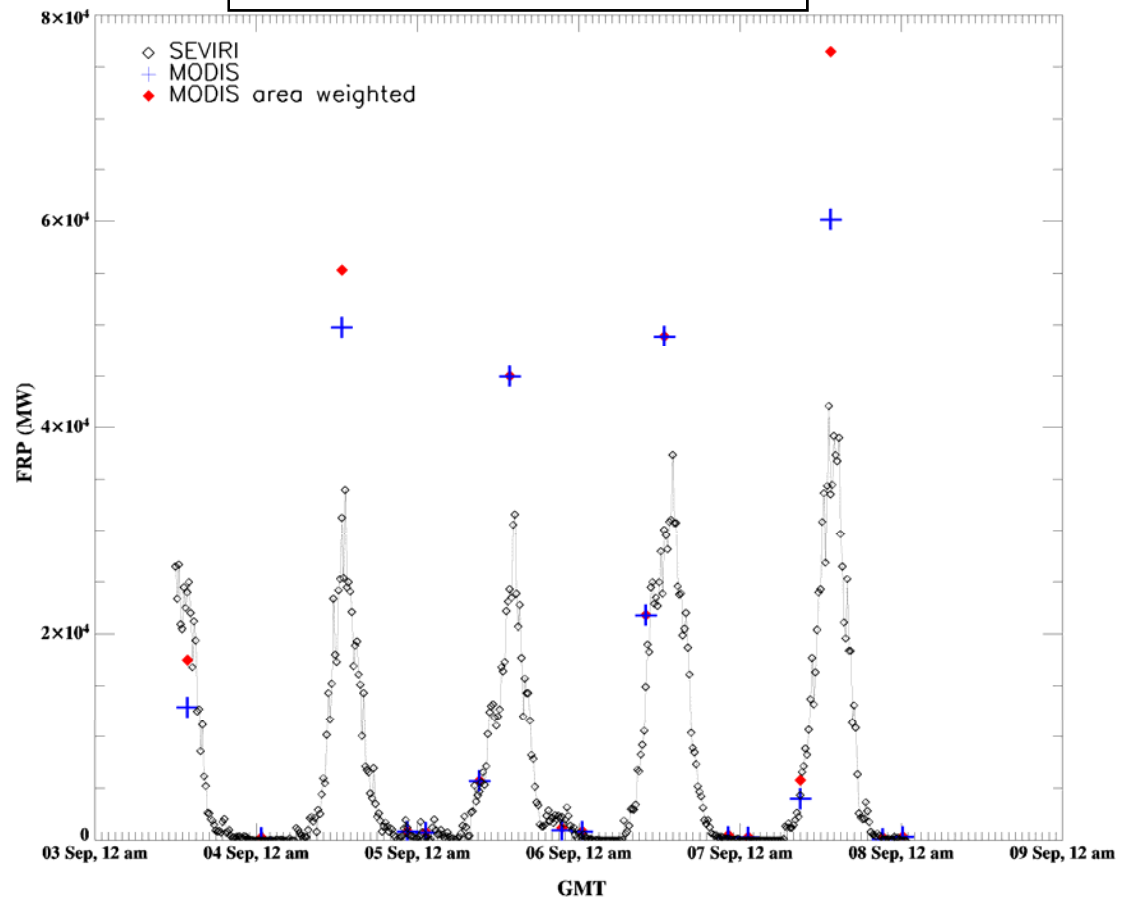
SEVIRI 5-Day Active Fire Mapping



15 mins frequency

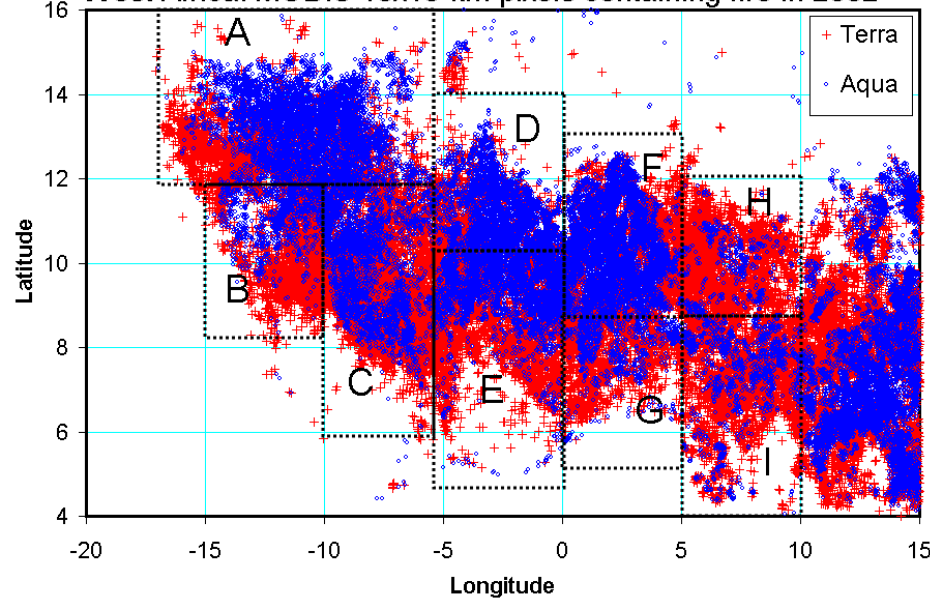


- ◇ SEVIRI observed
- + MODIS observed
- ◆ MODIS area-weighted

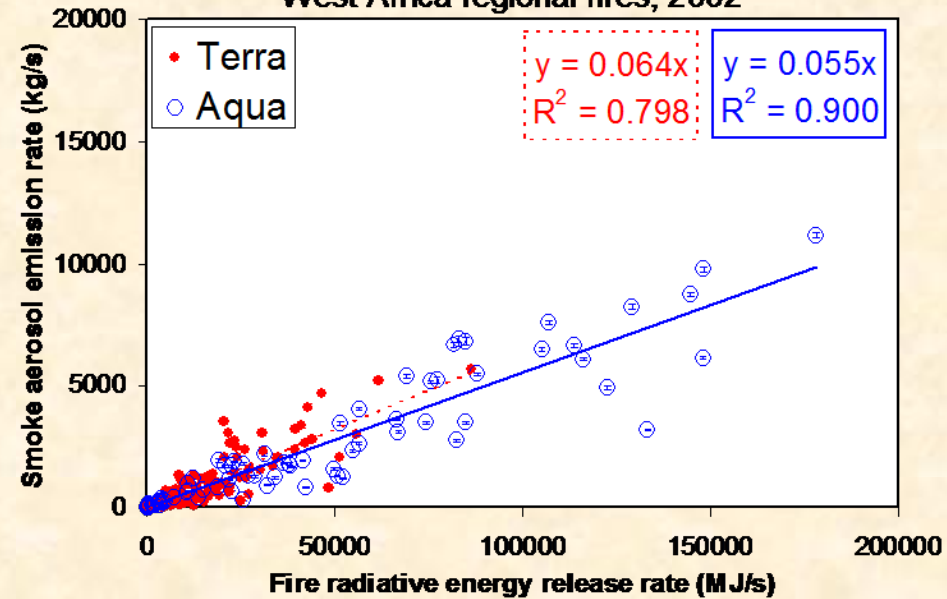


MODIS Regional Covariance between Fire Radiative Energy release rate and smoke aerosol emission rate (Slope is Coefficient of Emission, C_e)

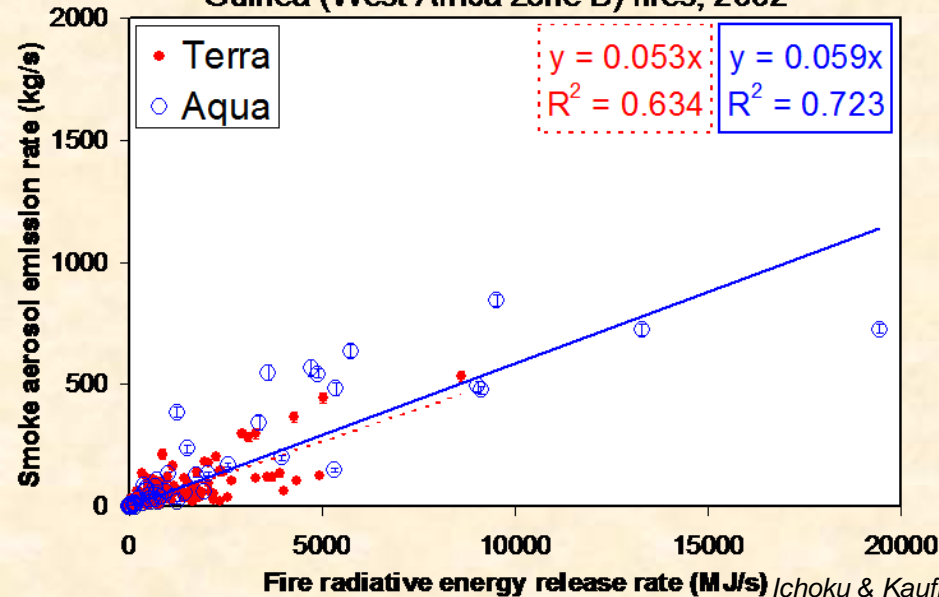
West Africa: MODIS 10x10-km pixels containing fire in 2002



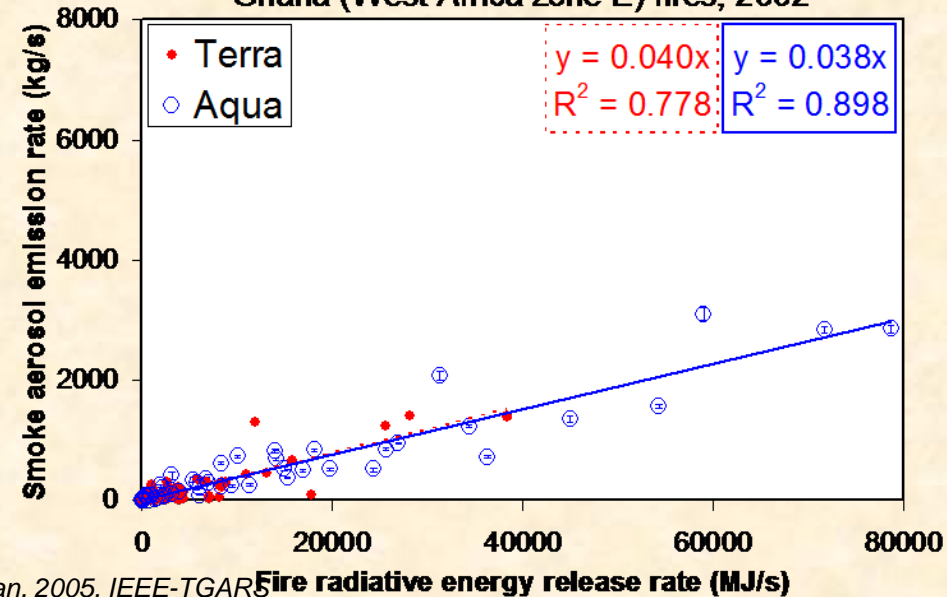
West Africa regional fires, 2002



Guinea (West Africa zone B) fires, 2002

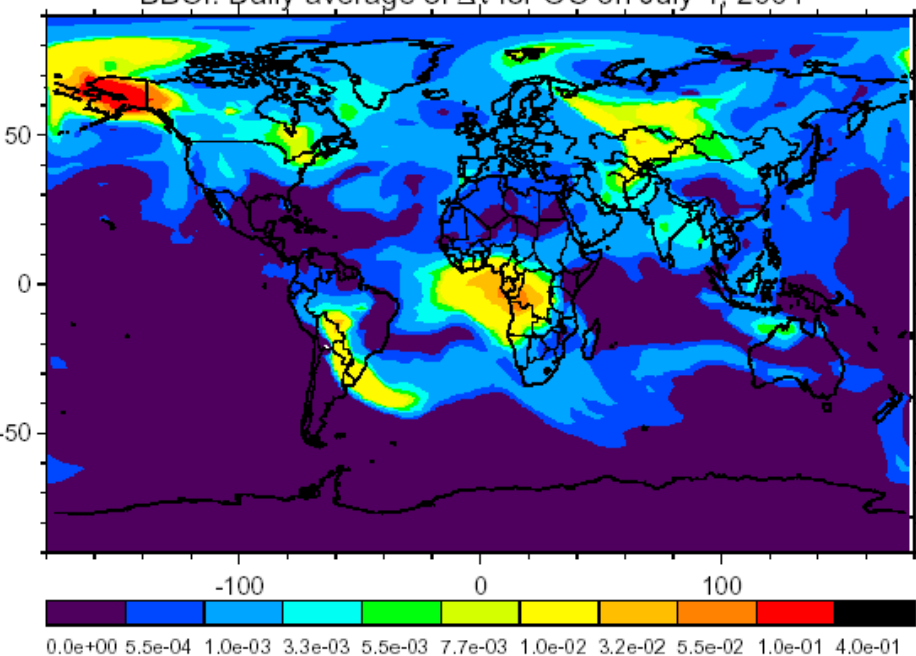


Ghana (West Africa zone E) fires, 2002

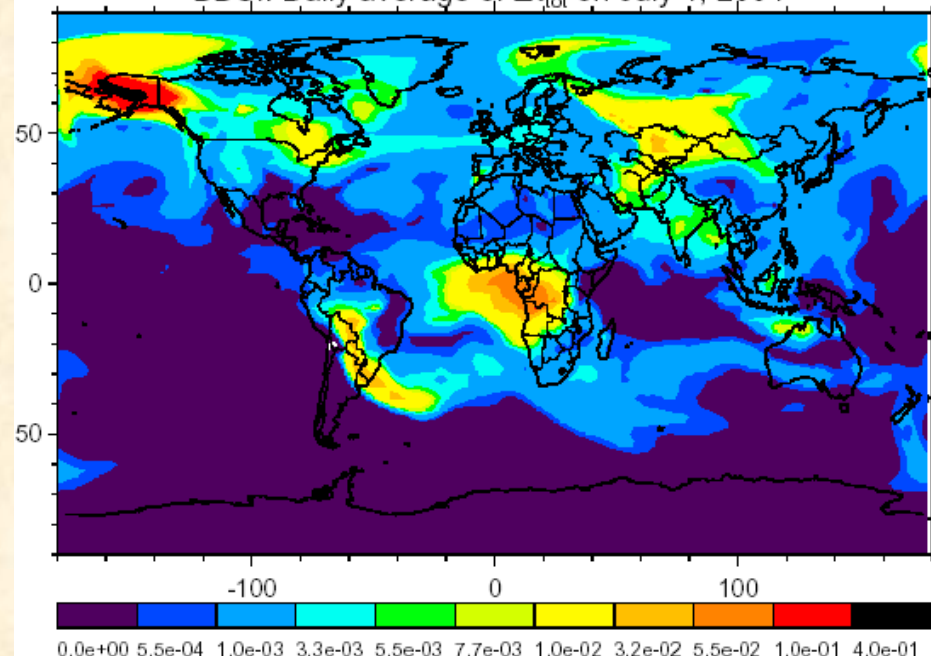


GOCART simulations of smoke emissions with MODIS Fire Radiative Power

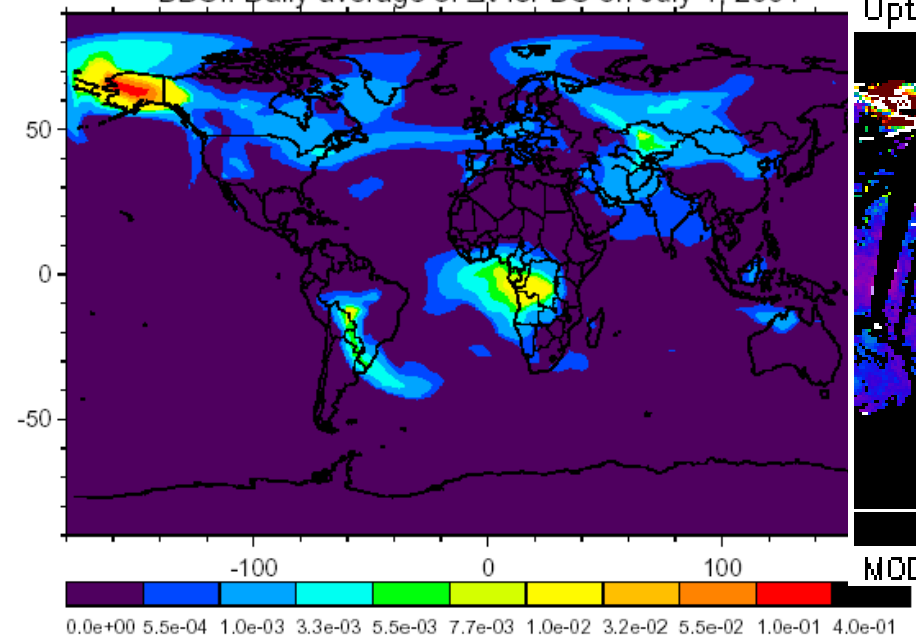
BBCI: Daily average of $\Delta\tau$ for OC on July 1, 2004



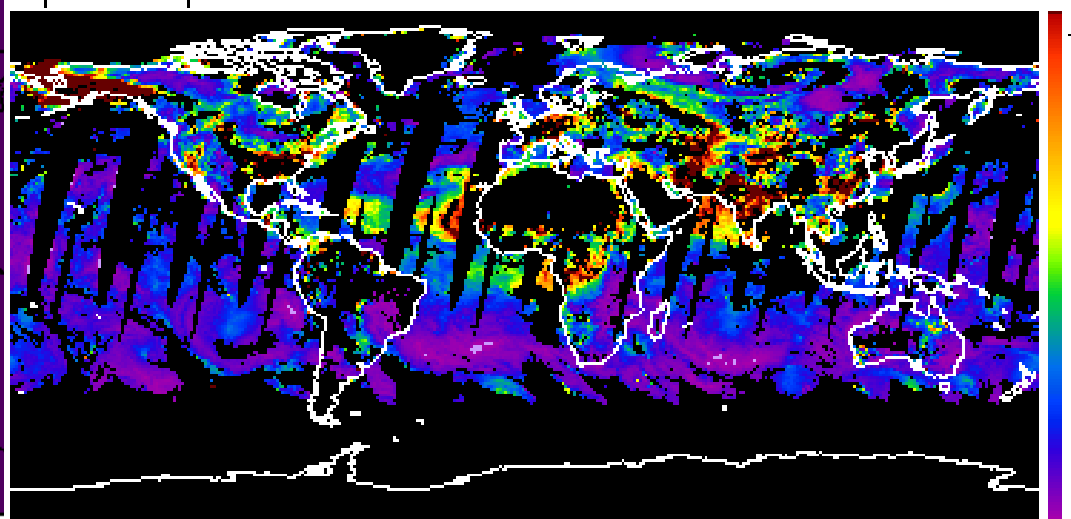
BBCI: Daily average of $\Delta\tau_{\text{tot}}$ on July 1, 2004



BBCI: Daily average of $\Delta\tau$ for BC on July 1, 2004



Optical_Depth_Land_And_Ocean_Mean



MODIS/Terra

MOD08_D3_A2D04183.D04.2004184-171925.hdf

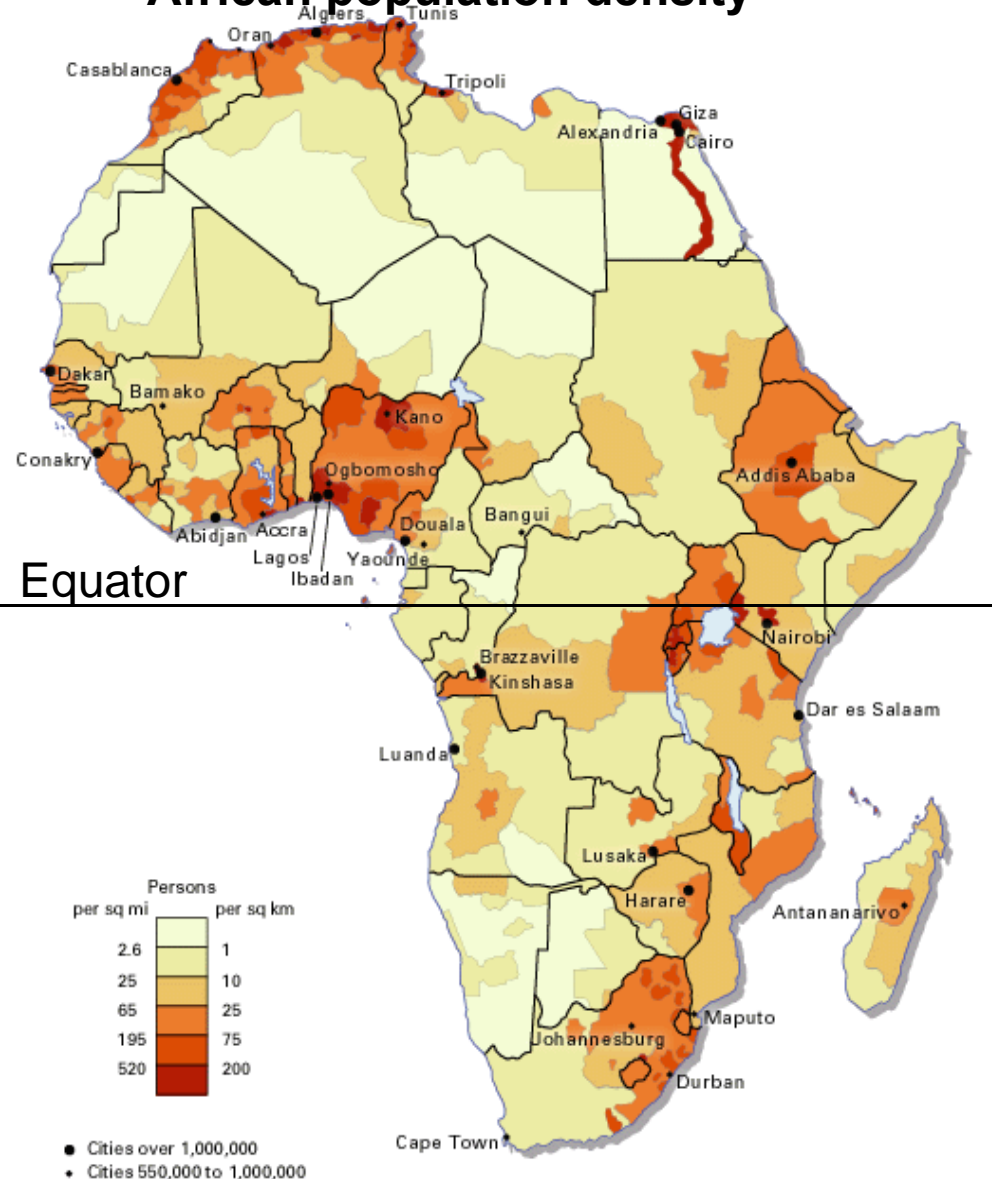
name

Advantages of MODIS+SEVIRI for Africa

- MODIS and SEVIRI are currently the only space-borne sensors that measure fire strength (i.e. Fire Radiative Power, FRP).
- MODIS covers the globe 4 times daily at strategic times, SEVIRI covers Africa every 15 minutes.
- MODIS measures FRP at 1-km resolution (good for biomass burning monitoring), SEVIRI measures at 4-km but data can be adjusted to fill up MODIS temporal gaps.
- Data products are free.
- SEVIRI can be acquired in real time. A reasonable investment in Direct Broadcast (DB) systems can ensure near real-time data availability from MODIS.
- MODIS-like sensor (VIIRS) on NPOESS will provide continuity for good spatial resolution.

What can we do ?

African population density



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Monitoring & Early Warning Systems for Africa

Site facilities of type SERVIR at Regional (not Local or National) Centers to cover the populated areas of Africa.

Well-coordinated strategic utilization of Earth Observation (EO) data to provide early warning and monitoring of the environment.

Engage the regional or international organizations actively to provide support and encourage application.

Advantages to Africa

- Share resources cost-effectively.
- Utilize EO for Societal Benefit.
- Mitigate adverse factors.

Conclusions

- Fire Radiative Power (FRP) from satellite is directly related to fire strength, biomass consumption, and smoke emissions.
- FRP is advantageous for estimating burned biomass and smoke emissions: quantitative, more direct, fewer assumptions, less uncertainty, higher accuracy, wide range of scales: spatial (local, regional, and global) and temporal (real-time, daily, monthly, etc.).
- Great potential for varied and far-reaching real-time and long-term applications: e.g. fire effects and pollutant dispersion forecasting for planning sustainable economic and environmental development.